

The Feasibility of Detecting a Magnetic Field From a Distant Platform

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FINAL REPORT

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The long term objective of the Remote Magnetic Sensing (REMAS) project is to study the feasibility of detecting a magnetic field from a distant platform. This can be contrasted with the current method of magnetic sensing that employs an ASQ-81 helium magnetometer housed in a P-3 aircraft. The ASQ-81 must be located within close proximity of the target in order to detect a field but the presence of the P-3 introduces the possibility of distorting the field and thereby invalidating the measurement. However, this dilemma can be circumvented if a remote sensing device is employed to accomplish the field measurements. The platform is removed from the target area and therefore cannot influence the field. An added advantage of remote sensing is its ability to generate a ^{two} 2-dimensional field map of the ocean's surface. These features make the study of systems capable of remotely sensing a magnetic field both a provocative and potentially profitable endeavor.

A potential candidate for use in a remote sensing system was suggested by Happer[1] in 1973. He recommend the use of Xe^{129} for the following reasons;



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- 1) Xe^{129} is universally present in the atmosphere with a density of 6×10^{11} atoms per cm^3 .
- 2) Xe^{129} is chemically inert and its concentration will not be affected by the local chemical conditions.
- 3) Xe^{129} probably has a nuclear magnetic relaxation time of several seconds in the atmosphere which is important in order to increasing the resolution of the sensor.
- 4) It may be possible to use a two-photon optical pumping procedure to polarize the Xe^{129} atoms.

An extensive study of xenon is currently underway in order to determine the feasibility of this remote sensing scheme. The remainder of this report will focus on the experimental work performed on xenon and also suggest new avenues of research that can be explored.

The isotope of xenon that is the subject of this research is Xe^{129} . It constitutes about 26% of all naturally occurring atmospheric xenon with about 6×10^{11} atoms per cm^3 . The mechanism employed to detect the magnetic field is a variation of Nuclear Magnetic Resonance (NMR). The Xe^{129} are first prepared by a pump pulse which leaves the atoms with a net magnetic moment. Then a second pulse excites the atoms causing them to fluoresce and thereby provides information about the magnetic field.

Xe^{129} has a nuclear spin of $1/2$ and under normal conditions the atoms are evenly distributed between the two spin states (up or down). The atoms can be optically pumped such that the ground state atoms are left predominately in either one of the two spin states. These atoms will now precess about the earth's magnetic field at the Larmor frequency of 1.178kHz/gauss [2] for Xe^{129} as shown in Fig. 1. Next the atoms are excited with subsequent pulses and the return fluorescence signals are modulated at the Larmor Frequency thereby providing the desired measurement of the magnetic field.

Early in the investigation a strong bidirectional emission signal was detected[3]. It is characterized by a threshold below which there is no bidirectional signal and above which there is a strong signal that depends linearly on the pump energy. The linear dependence is an unexpected result in light of the fact that the pumping is via a two-photon process and therefore a stimulated process is expected to depend quadratically upon the pump pulse. This anomaly is one of the many questions that will be addressed by this experiment.

The energy level diagram of Xe^{129} is shown in Fig. 2. The ground state of Xe^{129} is the $5p^6$ which is a closed shell. The atoms are excited via a two-photon process to a $6p$ state. A single photon transition between p states is dipole forbidden and a two-photon process is required. The pump

pulse transfers a portion of the ground state population to the upper state, 6p, from which it can decay to 6s states as shown in Fig. 3. The nature of the decay process, whether spontaneous or stimulated, depends on intensity and frequency of the pump pulse. Some of the processes that studied are Amplified Spontaneous emission(ASE) [4], four-wave mixing (FWM)[5] and stimulated electronic hyper-Raman Scattering (SEHRS)[6] to name a few.

The experimental layout is shown in Fig. 4. where the pump pulse is produced by a complicated procedure that requires the a dye laser, frequency doubling and finally a non-linear mixing of two laser pulses to produce radiation at ~250nm. A vacuum and gas mixing system is connected to the cell so that controlled amounts of xenon and buffer gas can be introduced into the cell. The beam splitter(BS) performs two functions; the first is to direct a portion of the pump beam into a photodiode (PD) in order to determine the energy of each pulse and the second is to direct the back emission signal into the photomultiplier tube (B-PMT). The beam is focussed in order to increase the power density of each pulse and the focal plane of the beam coincides with the center of the cell. The amount of side fluorescence is measured by a photomultiplier tube (T-PMT) placed perpendicular to the pump beam path which provides an indication of the lasers tuning.

A single shot of the pump pulse and back emission is shown in Fig. 5 where the back emission signal is delayed for

display purposes. A digital data collection system is able to collect the information from T-PMT, B-PMT and the PD so that both the side fluorescence and back emission can be plotted as a function of the pump beam as shown in Fig. 6 and Fig. 7. It is clear from the figures that the side fluorescence begins to increase quadratically and then becomes linear. The point at which this occurs is the threshold for the back emission process. It is obvious that the two processes are coupled but it is not clear how. One suggestion is that the two photon absorption process is being saturated and/or the absorption rate depends on the intensity of the back emission. These suggestions would explain the side fluorescence signal but the details need to be worked out thoroughly before a concrete connection can be made.

In order to determine the non-linear process occurring in the back direction a more exact knowledge of the frequency of the pump pulse and back emission is needed. The frequency information about the pump pulse can be indirectly obtained from knowledge of the dye laser's frequency. The dye laser can be pressure-tuned by the method described by Wallenstein and Hansch[7] continuously over a range of 150GHz with a bandwidth as low as 70MHz. The pump pulse's frequency is twice the dye laser's frequency because one of the processes required to generate the pump pulse is the frequency doubling of the dye laser. This provides detailed information about the frequency of the pump pulse. The frequency of the back emission is obtained by replacing the interference filter in

front of B-PMT with with a spectrometer with a resolution of at least 0.001nm.

The frequency information would then make it possible to unambiguously determine the nature of the back emission signal. The dependence of the back emission signal on the pump pulse's frequency would differentiate between ASE and SEHRS. Also the frequency of the back emission signal itself would provide concrete evidence for either one of the above processes. It is anticipated that in the next year these questions will be answered.

In addition to the above detailed work I have also participated in a two day training session in the use of Symbolic Manipulation Programming (SMP). SMP is a computer program capable of solving algebraic expressions symbolically. Other activities include interfacing the ITTextra computers to our experiment for data collection and analysis. Finally, a manuscript is in preparations for submission to the Review of Scientific Instruments concerning the digitizing of single shot spectra of our laser.

FIGURE CAPTIONS

Figure 1. The Earth's magnetic field, B , is in the Z-direction and the nuclear magnetic moment, M , is shown pointing in an arbitrary direction. The nuclear magnetic moment perpendicular to the Earth's field will precess at the Larmor frequency.

Figure 2. The energy level diagram of Xenon.

Figure 3. The energy level diagram of Xenon showing only those states involved in the emission process.

Figure 4. The experimental layout. YAG is the Nd-YAG laser, DL is the dye laser, WEX is the wavelength extender, BS is the beam splitter, D is the photodiode, B-PMT and T-PMT are the back and transverse photomultiplier tube. The cell is connected to the gas handling system to control the concentration of Xenon admitted into the cell. The B-PMT, T-PMT and D are all connected to the data collection system. YAG, DL and WEX are collectively called YAG-2.

Figure 5. A single shot of the pump pulse and the back emission. The concentration of xenon is 0.066mTorr in 20 Torr of Nitrogen. The scale for the pump pulse and back emission are 100mv/div and 5mv/div. The time scale is 20nsec/div.

Figure 6. A plot of the side fluorescence energy vs pump pulse energy for 2000 data points

Figure 7. A plot of the back emission energy vs pump pulse energy for 2000 data points

ENDNOTES

- 1 Happer, W., "Laser Remote Sensing of Magnetic Fields in the Atmosphere by Two-Photon Optical Pumping of Xe^{129} ", NADC Report N62269-78-M-6957 (1978)
- 2 Weast, R. C. ed., CRC Handbook of Chemistry and Physics, 63rd Edition, pg E-67 (1983)
- 3 Rankin, M. B., Bobb, L., Hall, R. & Davis, J., "Superradiant 6p-6s Emission in Xenon", JOSA, Vol. 1, No. 12, pg 1256 (1974)
- 4 Allen, L. & Peters, G. L., "Amplified Spontaneous Emission and External Signal Amplification in an Inverted Medium", Phy. Rev. A, Vol. 8, No. 4, pg. 2031 (1973)
- 5 Kirilenko, E. K., Lesnik, S. A., Markov, V. B. & Khyzniak, A. I., "Forward Four-beam Mixing in Sodium Vapor", Opt. Comm, Vol. 60, No. 1,2, pg. 9 (1986)
- 6 Cotter, D, Hanna, D. C., Tuttlebee, W. H. W., & Yuratich, M. A., "Stimulated Hyper-Raman Emission From Sodium Vapor", Opt. Comm., Vol. 22, No. 2, pg. 190 (1977)
- 7 Wallenstein, R. & Hansch, T. W., "Linear Pressure Tuning of a Multielement Dye Laser Spectrometer", Appl. Opt., Vol. 13 No. 7, pg. 1625 (1974)

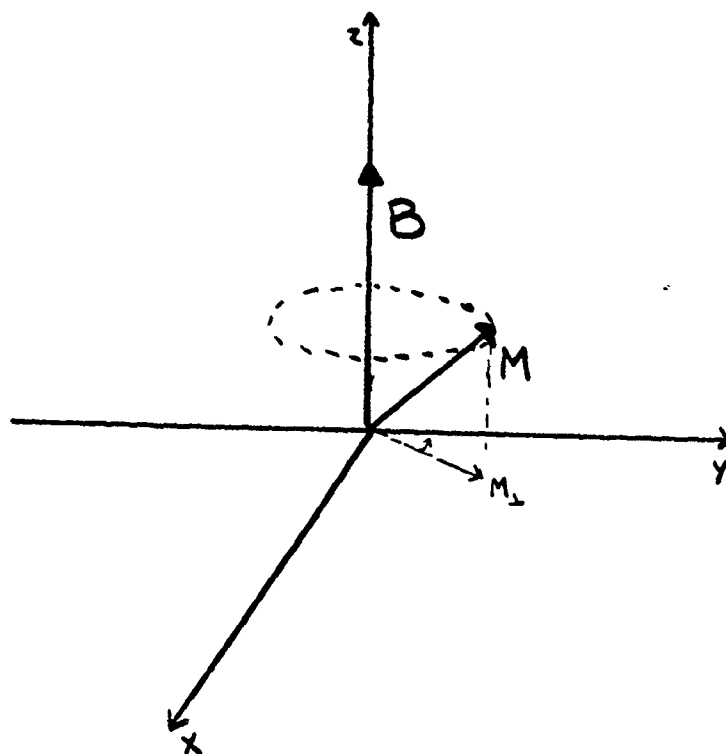


Figure 1

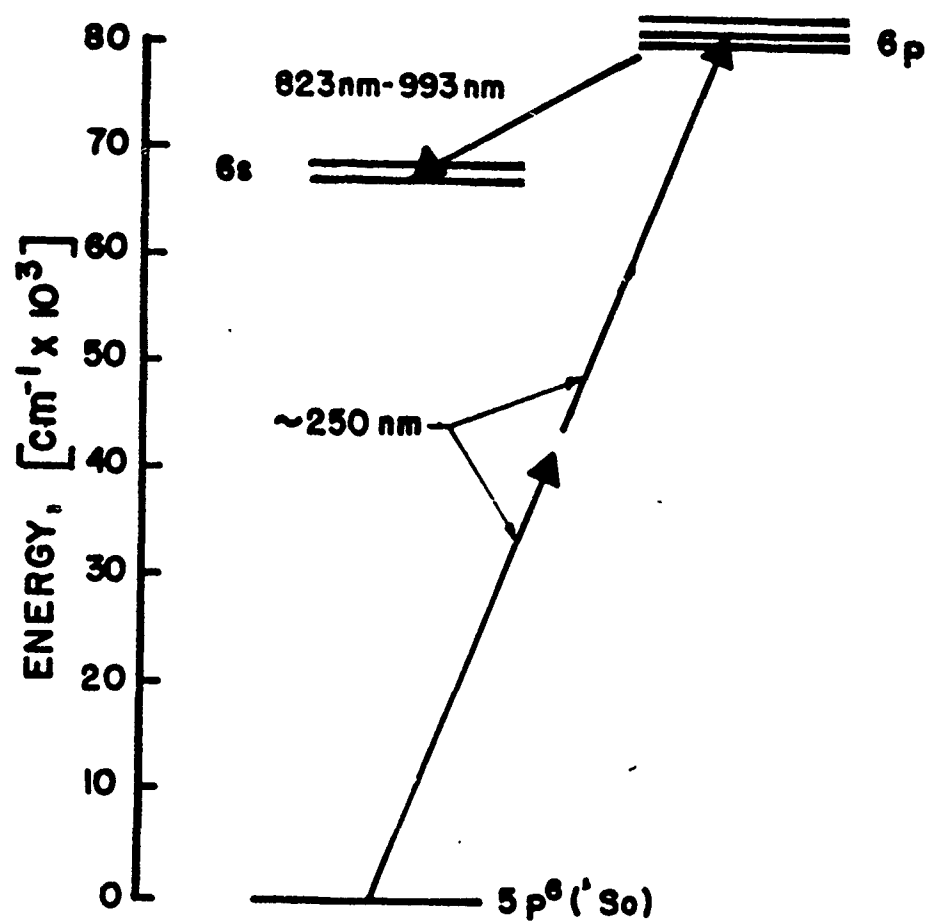


Figure 2

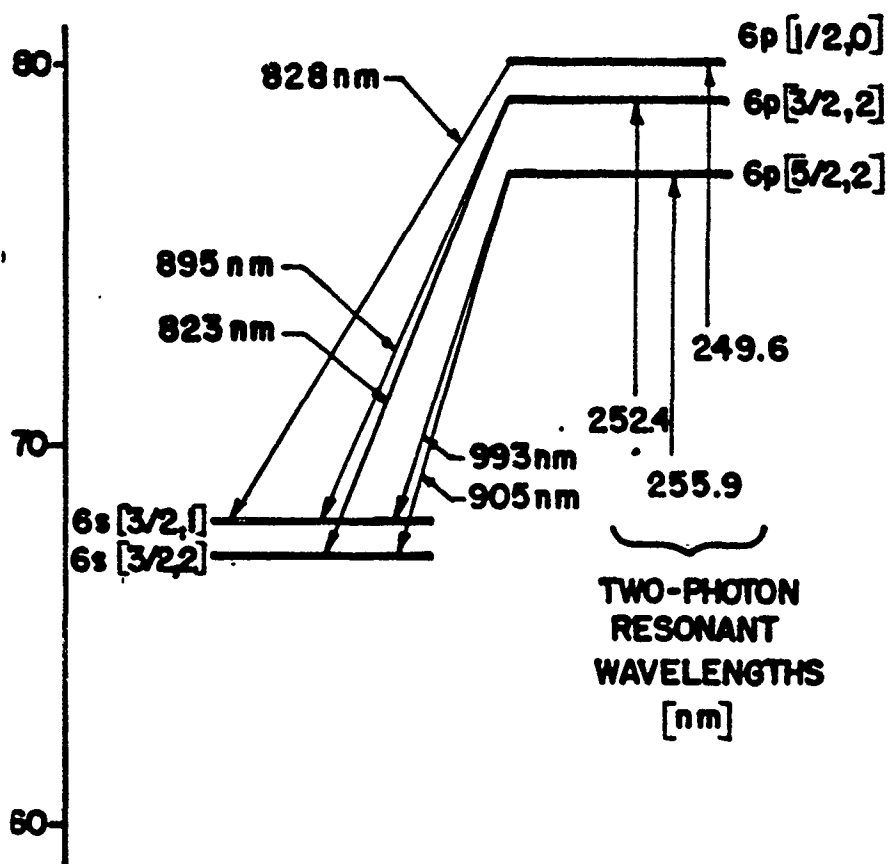


Figure 3

YAG-2

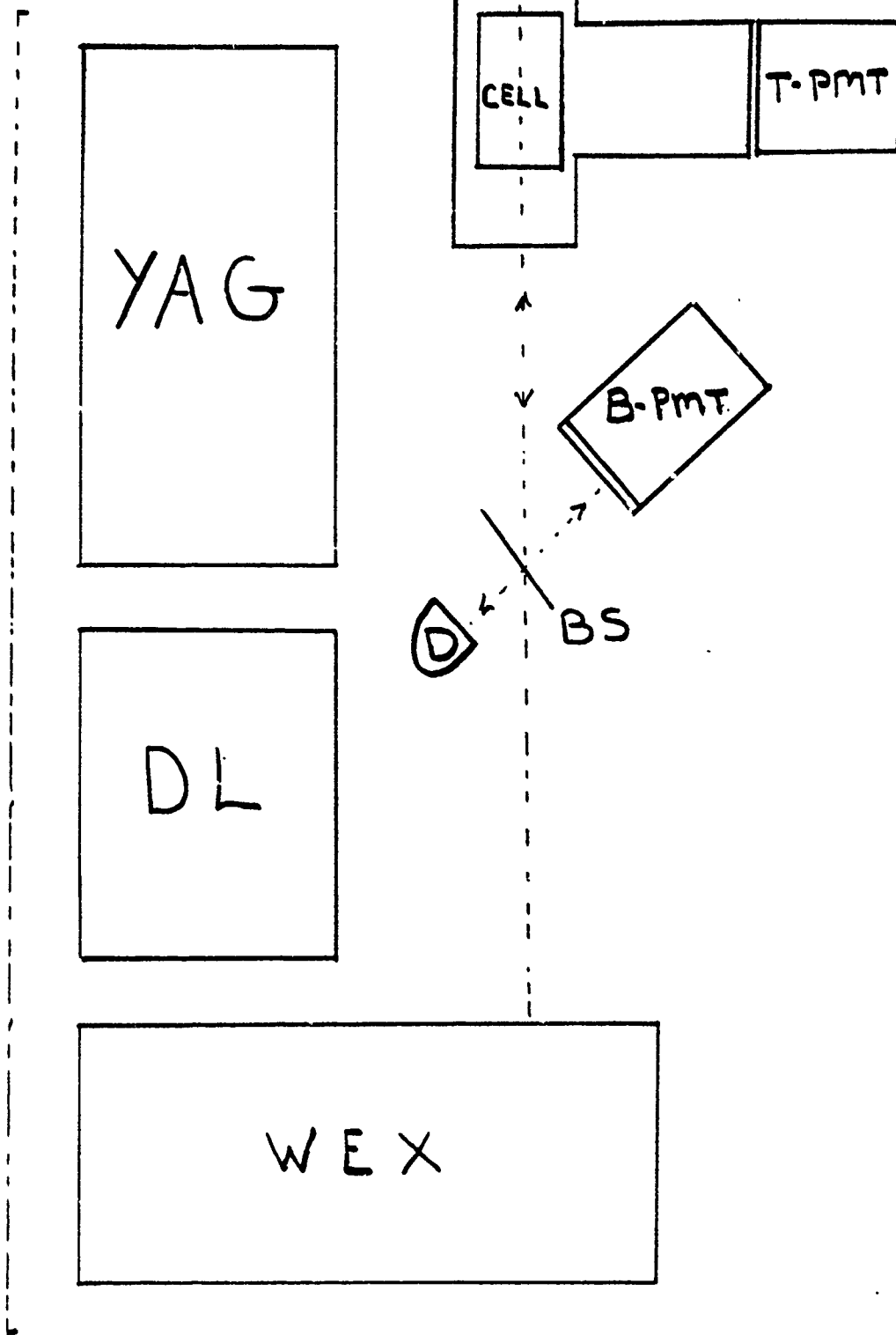


Figure. 4

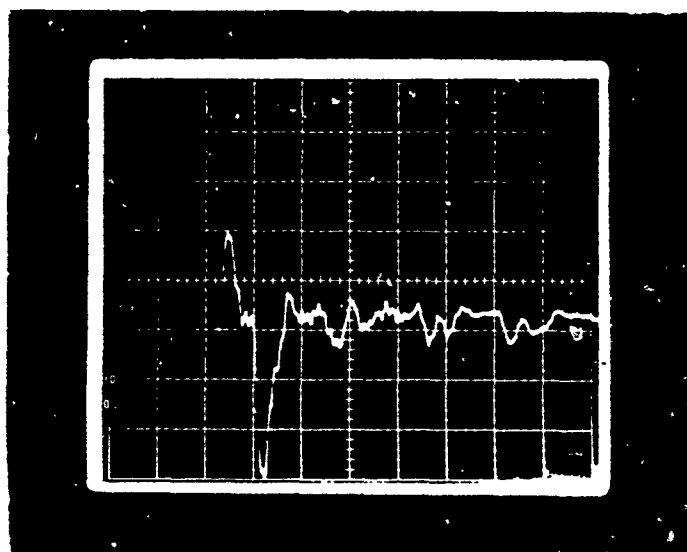


Figure 5

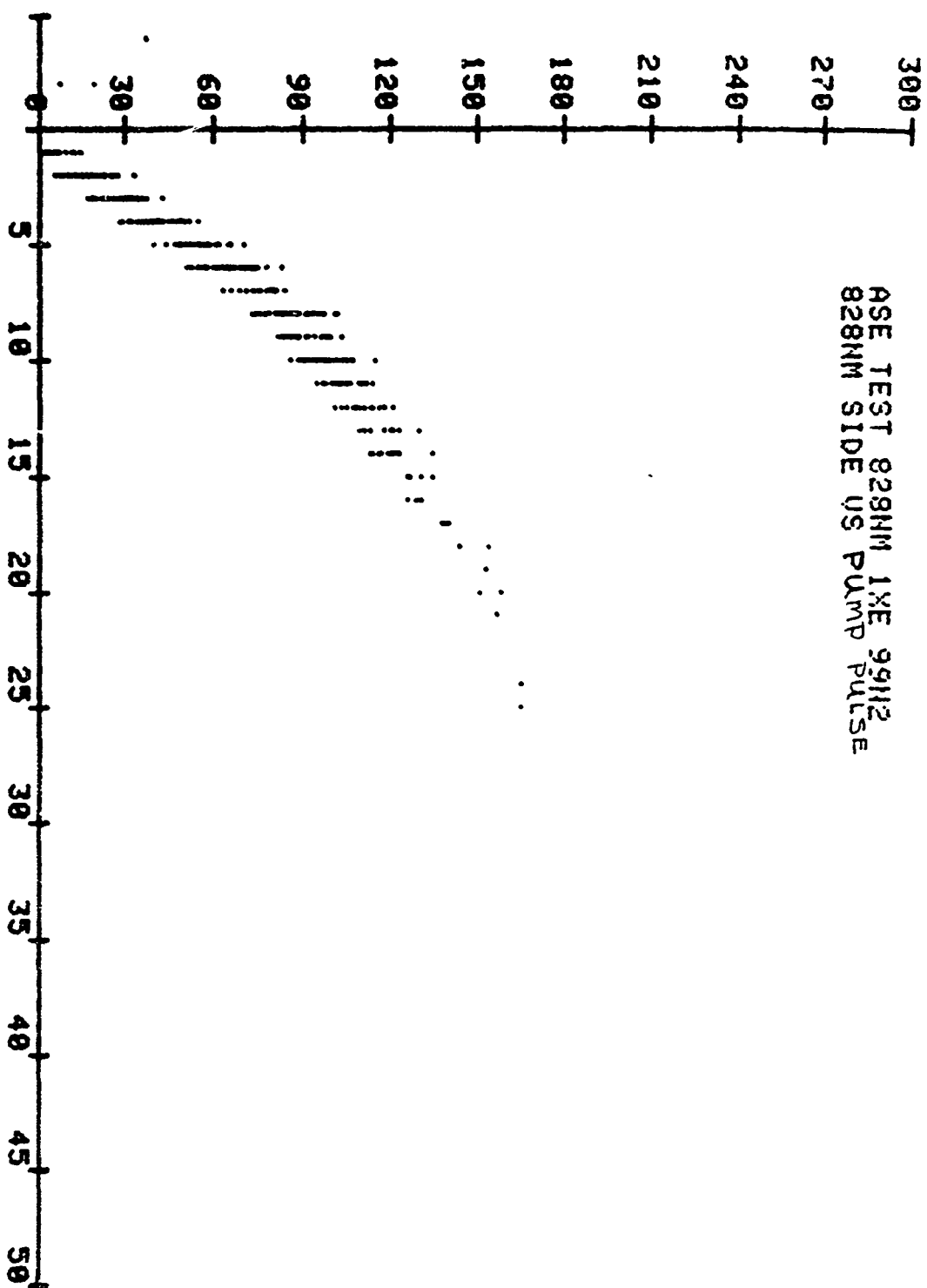


Figure 6

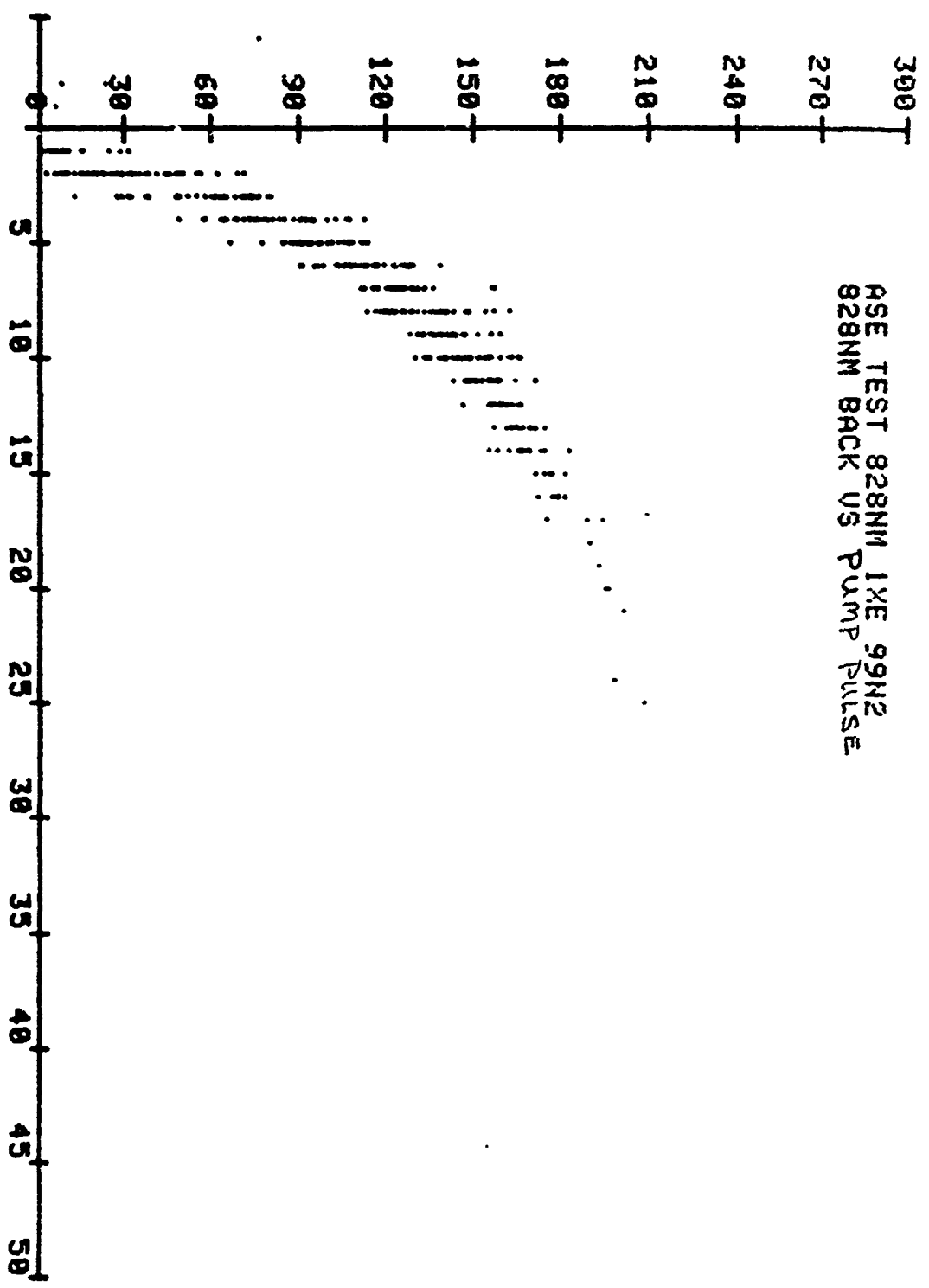


Figure 7